Optimal Undervoltage Load Shedding using Ant Lion Optimizer

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Abstract — This paper presents an optimal Undervoltage Load Shedding (UVLS) scheme using Ant Lion Optimizer (ALO). This approach utilized the concept of hunting mechanism of ant lions in nature consisting of five steps of hunting prey such as random walk of ants, building traps, entrapment of ants in traps, catching preys and re-building traps. The location of load to be shed is identified based on voltage stability index. Voltage stability index is a good indicator for monitoring the critical bus. The ALO is employed to search for the best amount of load to be shed for power loss minimization and voltage profile improvement. The effectiveness of the proposed technique is illustrated in IEEE 30-bus Reliability Test System. The results show better performance in terms of voltage profile improvement, power loss minimization and stability improvement after performing under voltage load shedding using Ant Lion Optimizer.

Keywords - Ant Lion Optimizer; Under Voltage Load Shedding; Voltage Stability; Power Losses

I. INTRODUCTION

Voltage collapse phenomenon is known to be complex and localized in nature but with a widespread effect. The ultimate effect of voltage collapse would be total system collapse which would incur high losses to utility companies [1]. Voltage collapse is one of scenario to indicate the condition of the existing and contingencies for some part of the electrical system including power generation and transmission and has been operated beyond its capability [2]. Voltage collapse has much more serious consequences such as complete blackout which can occur when there is too much demand and too little supply. Many countries and cities in other parts of the world have experienced complete blackouts. Blackouts have a profound impact on people’s daily life such as economic loss where many factories cannot operate, traffic control problem and safety of social facilities such as hospitals, communication of internet and other communications systems break down. If this occurs in urban areas this is a disaster because it involves millions of users [3].

Load shedding, or load reduction, is implemented as a controlled option to respond to unplanned events in order to prevent the power system from blackout. The purpose of proper countermeasure needed by system planning and operating is to maintain the system reliability and stability when contingencies happen unexpectedly [4]. Ref [5] presents about the type of countermeasures for voltage collapse and propose load shedding as the last option to prevent voltage collapse occurring in the system. Load shedding can be classified into two scheme which Under frequency load shedding (UFLS) and Under voltage load shedding (UVLS) [6]. UVLS is known as the ultimate countermeasure to improve a voltage in an unstable system, where there is no method to prevent voltage collapse [7].

Several methods have been proposed in [3] viewing voltage stability analysis such as Q-V curves and P-V curves. Some researchers used P-V and Q-V curves as indicator on how close the system from voltage collapse. Whereas, the other researchers developed voltage stability indices as indicators. Reference [8] intensely show the most contribution factor of blackouts is the voltage unstable system arising from the overloading of transmission system. During overloading conditions, an accurate load shedding is crucial to prevent total system collapse. Conventional load shedding techniques cannot deal efficiently with modern
and complex power systems and do not provide optimum load shedding. Improper load shedding has led to a high number of power blackouts due to surplus or insufficient load shed, this has questioned the ability and reliability of existing conventional load shedding techniques [9]. On the other hands, excessive load shedding will trip the load too much and will cause an unnecessary power outage problem [10].

Thus, an efficient load shedding technique is needed to shed optimum load and maintain power system stability. A lot of computational intelligence technique has been introduced since the late 1980s [7]. Recently, computational intelligence techniques have attracted the researchers’ attention due to their robustness and ability to deal with complex systems easily such as Genetic Algorithm, Evolutionary Programming, Quantum-Inspired Evolutionary Programming, Ant Colony Optimization and particle swarm optimizations [9]. These techniques can easily solve those nonlinear, multi objective problems in power systems that cannot be solved by the conventional methods. However, the disadvantage of these techniques is longer computation time. Therefore, this paper proposes an optimal undervoltage load shedding using Ant Lion Optimizer (ALO) algorithm.

II. VOLTAGE STABILITY INDEX

In this paper, the location of load to be shed is identified based on Voltage Stability Index. Voltage stability index is the measuring instrument in predicting the voltage stability condition in the system. Voltage stability index, L is formulated from Improved Disflow Technique [11]. The formula are shown in (1).

\[ L = \frac{4(V_{o}V_{L}-V_{L}^2)}{V_{o}^2} \]  

Where,  
L = voltage stability index  
\( V_{o} \) = no load voltage  
\( V_{L} \) = load voltage

The value of L at any bus must be kept less than 1.0 in order to maintain the voltage stability in a system. If the value of L assesses prone to 1.0, the voltage at evaluated bus going to be unstable condition [11]. Five buses with highest index were selected as the location of load to be shed.

III. ANT LION OPTIMIZER (ALO)

Ant Lion Optimizer (ALO) is a novel nature-inspired algorithm proposed by Seyedali Mirjalili in 2015 [12]. The ALO algorithm mimics the hunting mechanism of ant lions in nature. Five main steps of hunting prey such as the random walk of ants, building traps, entrapment of ants in traps, catching preys, and re-building traps are implemented. Ant lion is a type of insect in class of net-winged or Neuroptera order. There are two main phases of ant lions lifecycle: larvae and adult that consists of a natural total lifespan up to 3 years, which mostly occurs in larvae (only 3–5 weeks for adulthood). Prior adulthood, ant lions undergo metamorphosis in a cocoon. During the larvae phase, ant lions mostly hunt. The adulthood period is for reproduction. To hunt insects such as ants, the ant lion larva will build a trap by digging a cone shaped pit in sand. This is done by moving along a circular path and tossing out sands with its jaw. Then, the larva hides underneath the bottom of the cone and waits for insects to be trapped in the pit. The edge of the cone is sharp enough for insects to fall to the bottom of the trap easily. Finally, the ant lion will catch its prey in the trap. Once the ant lion realizes that a prey is in the trap, it tries to catch it.

A. Random walks of ants

Random walks are all based on the Eq.

\[ X(t) = \begin{bmatrix} 0, \text{cumsum}(2r(t_1)-1), \text{cumsum}(2r(t_2)-1), \ldots, \text{cumsum}(2r(t_n)-1) \end{bmatrix} \]  

Where \( \text{cumsum} \) calculates the cumulative sum, \( n \) is the maximum number of iteration, \( t \) shows the step of random walk and \( r(t) \) is a stochastic function defined as follows:

\[ r(t) = \begin{cases} 1 & \text{if } \text{rand} > 0.5 \\ 0 & \text{if } \text{rand} \leq 0.5 \end{cases} \]  

In order to keep the random walks inside the search space, they are normalized using the following equation (min–max normalization):

\[ X'_i = \frac{(X_i - a_i) \times (d_i - c_i)}{(d_i - a_i)} + c_i \]  

Where \( a_i \) is the minimum of random walk of i-th variable, \( d_i \) is the maximum of random walk in i-th variable, \( c_i \) is the minimum of i-th variable at t-th iteration, and \( d_i \) is the maximum of i-th variable at t-th iteration.

B. Trapping in ant lion’s pits

Random walks of ants are affected by antlions’ traps. In order to mathematically model this assumption, the following equations are proposed:

\[ C_j^{t+1} = \text{Antlion}_j^{t+1} + C_i^{t} \]  
\[ d_j^{t+1} = \text{Antlion}_j^{t+1} + d^t \]  

where \( C_i^{t} \) is the minimum of all variables at t-th iteration, \( d^t \) indicates the vector including the maximum of all variables at t-th iteration, \( C_j^{t+1} \) is the minimum of all variables for i-th
ant, \(d'\) is the maximum of all variables for \(i\)-th ant, and \(\text{Antlion}_j^t\) shows the position of the selected \(j\)-th antlion at \(t\)-th iteration.

C. Building trap

The ALO algorithm is required to utilize a roulette wheel operator for selecting ant lions based of their fitness during optimization. This mechanism gives high chances to the fitter ant lions for catching ants.

D. Sliding ants towards ant lion

With the mechanisms proposed so far, ant lions are able to build traps proportional to their fitness and ants are required to move randomly. For mathematically modelling this behavior, the radius of ants' random walks hyper-sphere is decreased adaptively. The following equations are proposed in this regard:

\[
c^t = \frac{c^t}{l} \\
d^t = \frac{d^t}{l}
\]

(6)

where \(l\) is a ratio, \(c^t\) is the minimum of all variables at \(t\)-th iteration, and \(d^t\) indicates the vector including the maximum of all variables at \(t\)-th iteration.

E. Catching prey and re-building the pit

The final stage of hunt is when an ant reaches the bottom of the pit and is caught in the antlion’s jaw. After this stage, the antlion pulls the ant inside the sand and consumes its body. It is assumed that catching prey occur when ants becomes fitter (goes inside sand) than its corresponding antlion. An antlion is then required to update its position to the latest position of the hunted ant to enhance its chance of catching new prey. The following equation is proposed in this regard:

\[
\text{Antlion}_j^t = \text{Antlion}_j^t \text{ if } f(\text{Antlion}_j^t) > f(\text{Antlion}_j^t) \\
\]

(7)

where \(t\) shows the current iteration, \(\text{Antlion}_j^t\) shows the position of selected \(j\)-th ant lion at \(t\)-th iteration, and \(\text{Antlion}_j^t\) indicates the position of \(i\)-th ant at \(t\)-th iteration.

F. Elitism

Elitism is an important characteristic of evolutionary algorithms that allows them to maintain the best solution(s) obtained at any stage of optimization process. Since the elite is the fittest antlion, it should be able to affect the movements of all the ants during iterations. Therefore, it is assumed that every ant randomly walks around a selected antlion by the roulette wheel and the elite simultaneously as follows:

\[
\text{Antlion}_j^t = \frac{R_j^t + R_j^t}{2}
\]

(8)

where \(R_j^t\) is the random walk around the antlion selected by the roulette wheel at \(t\)-th iteration, \(R_j^t\) is the random walk around the elite at \(t\)-th iteration, and \(\text{Antlion}_j^t\) indicates the position of \(i\)-th ant at \(t\)-th iteration[16]. The overall procedure to determine the optimal amount of load to be shed is simplified in the form of flowchart as shown in Fig. 1.

IV. PROBLEM FORMULATION

In this paper, the optimal location of load shed is identified based on voltage stability index as described in section III. The optimal amount of load to be shed is identified by using Ant Lion Optimizer (ALO) optimization technique. The objective of the objective function is power loss minimization. Power losses are minimized based on (5).

\[
\min \sum_{i=1}^{M} P_{loss,i}
\]

(8)

where, \(n\) = number of lines in the system voltage constraint, \(V_{\text{min}} < V_i < V_{\text{max}}\)

The optimization also took into consideration the following constraints:

Load curtailment limits:

\[
0 \leq P_{\text{shed},i} \leq P_{L,i} \quad \text{and} \quad 0 \leq Q_{\text{shed},i} \leq Q_{L,i}
\]

(9)

(10)

where \(P_{\text{shed},i}\) is the amount of load to be shed at bus \(i\) in MW, \(P_{L,i}\) is the amount of load at bus \(i\) in MW, \(Q_{\text{shed},i}\) is the amount of load to be shed at bus \(i\) in Mvar and \(Q_{L,i}\) is the amount of load at bus \(i\) in Mvar.

Voltage limits:

\[
V_{\text{min}} < V_i < V_{\text{max}}
\]

(11)

where \(V_{\text{min}}\) is the minimum voltage 0.90 p.u. and \(V_{\text{max}}\) is the maximum voltage 1.05 p.u.
V. RESULTS AND DISCUSSION

The proposed technique is tested on IEEE 30-bus reliability test systems as shown in Fig. 2. The test system consists of six machines and an infinite bus. The disturbance considered was the overloading conditions. Three cases were considered:

- P increase
- Q increase
- Both P and Q increase

Fig. 3 shows the minimum voltage obtained at different load factor for the three cases; increase both P and Q, increase P only, increase Q only. From the results, the load factor of 1.8pu is chosen for implementing undervoltage load shedding scheme.

In this paper, the locations of load shed are identified based on the highest value of voltage stability index (L). The value of L assesses close to 1.0 indicate that the voltage at evaluated bus going to be unstable condition. Five buses with highest index were selected as the location of load to be shed. Table 1 shows the five weakest buses after performing voltage stability index (L) for all cases of load increment. From the results tabulated in Table 1, it can be seen that the highest value of L was obtained at bus 30 for overall P and Q load increase. This indicates voltage collapse is prone to occur at bus 30 since its L factor is closes to 1.0. The buses chosen for load shed in all cases are bus 30, 26, 29 and 24.
Ant Lion Optimizer (ALO) algorithm is used to optimize amount of load shed in order to minimize power losses while maintaining voltage profile into acceptable level. The iterations performed for each test case are 500 and number of search agents (population) taken in all cases is 20. Fig. 4 illustrates the convergence curve for PQ load increase. ALO converged at 367\textsuperscript{th} iteration with an optimal value of 60.6471MW. ALO is also applied for other cases. The comparative results before and after implementation of UVLS in terms of power losses and minimum voltage are presented in Fig. 5 and Fig. 6 respectively.

### Table 1. L Index at 1.8 Load Factor

<table>
<thead>
<tr>
<th>RANKING</th>
<th>BUS NO</th>
<th>L index</th>
<th>P increase</th>
<th>Q increase</th>
<th>PQ increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>0.6572</td>
<td>0.3370</td>
<td>0.7858</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>26</td>
<td>0.5264</td>
<td>0.3069</td>
<td>0.6991</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>29</td>
<td>0.5117</td>
<td>0.3054</td>
<td>0.6529</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>0.4730</td>
<td>0.2949</td>
<td>0.6406</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>19</td>
<td>0.4663</td>
<td>0.2715</td>
<td>0.6272</td>
<td></td>
</tr>
</tbody>
</table>

From the results obtained in Fig. 5, it could be observed that total power loss is reduced for all cases after implementing UVLS using ALO. Similar observation also can be seen in Fig. 6 where the minimum voltage has been increased for all cases. The optimal amount of load shed is tabulated in Table 2.

### Table 2. Optimal Amount of Load Shed

<table>
<thead>
<tr>
<th>Case</th>
<th>Pshed (MW)</th>
<th>BUS 30</th>
<th>BUS 29</th>
<th>BUS 26</th>
<th>BUS 24</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>9.1412</td>
<td>3.3877</td>
<td>1.6667</td>
<td>4.6064</td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>0.082373</td>
<td>4.6572</td>
<td>0.1269</td>
<td>4.0028</td>
<td></td>
</tr>
<tr>
<td>PQ</td>
<td>8.8863</td>
<td>2.2675</td>
<td>0.8321</td>
<td>8.418</td>
<td></td>
</tr>
</tbody>
</table>

### VI. CONCLUSION

This paper presents a new approached for determining the optimal undervoltage load shedding scheme in power system. The location of the load to be shed was determined using voltage stability index. The voltage stability index has capability in determining the critical load buses that have high tendency to cause the system collapse. Then, the optimal amount of load to be shed was determined by Ant Lion Optimizer (ALO) technique. The ALO algorithm is based on the hunting mechanism of ant lions in nature. There are five steps of hunting prey are implemented such as the random walk of ants, building traps, entrapment of ants in traps, catching preys, and re-building traps. Based on the simulation result, it can be observed that by shedding an appropriate amount of load at the most critical bus are able to improve the system performance in terms of power loss minimization and voltage profile improvement.

### ACKNOWLEDGMENT

The authors would like to thank the Research Management Institute (RMI), Universiti Teknologi MARA, Malaysia and the Ministry of Higher Education (MOHE),
Malaysia through research grant 600-RMI/FRGS 5/3 (142/2015) for the financial support to this research.

REFERENCES